Full-scale Application of a Dimensional Quality Assessment Technique to Precast Concrete Panels using Terrestrial Laser Scanning

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ABSTRACT

Nowadays, precast concrete panels are one of the most popular construction components. To safeguard the overall quality of construction projects, it is important to ensure that the dimensional quality of precast concretes conform to the design specifications. In order to achieve this, a terrestrial laser scanning (TLS)-based automated dimensional quality assessment technique has been developed by the author's group. The scope of this paper is such that the developed dimensional quality assessment technique is further advanced so that this technique can also be applied to full-scale precast concrete panels with complex geometries. A full-scale precast slab with dimensions of 10,610 mm × 1,980 mm in a precast manufacturing company is used as a test target to validate the effectiveness of the dimensional quality assessment technique. The challenges encountered during the data analysis of the full-scale test are investigated and resolved using optimized algorithms. Furthermore, comparison of the effectiveness between the conventional technique (deviation analysis) and the proposed technique is conducted. The average dimensional error for the proposed technique is 5.2 mm, while that of the conventional deviation analysis is 10.2 mm, demonstrating that the proposed technique can have high potentials in estimating and assessing the dimensional properties of the precast concrete panel.

INTRODUCTION

Over the last few decades, precast concrete panels have become a popular component in the construction industry. Compared to site-cast construction, precast concrete panels allow for faster production, lower cost, and a more efficient assembly of elements. Despite these benefits, the use of precast concrete panels could suffer from unexpected construction delays and system failures if their dimensional quality is not assessed properly. It is reported that 5-16 % of the construction cost is spent on fixing the problems associated with poor quality components detected at the last stage of construction (Burati and Farrington 1987). Hence, it is important to ensure that the dimensions and the quality of the precast concrete panels conform to their design specifications. Currently, the dimensional quality assessment of precast concrete panels relies largely on manual inspections, which are time consuming and costly. Also, inspection results are subjective and may not be reliable. Recently, terrestrial laser scanner (TLS) has gained much attention in the discipline of civil engineering, as it allows for prompt acquisition of spatial information of a target object surface and a long measurement range with millimeter-level accuracy. Because of these advantages, TLS has been widely used in a variety of civil engineering applications including 3D modeling of structures (Bernardini and Rushmeier 2002), deflection and deformation monitoring (Park et al. 2007), and heritage preservation (Yastikli 2007). In terms of the quality assessment of concrete structures, previous studies have mainly focused on the deviation analysis between as-is models and as-built models (Akinci et al. 2006) and the detection of damage such as cracks, flatness and volume loss (Teza et al. 2009; Tang et al. 2011; Olsen et al. 2010). However, despite its practical importance, little attention has been paid to the dimensional estimation of precast concrete panels.

In order to assess the dimensional quality of precast concrete panels in an automated and reliable manner, a TLS-based technique has been developed and applied to a small size of concrete panel by the author's group (Kim et al. 2013). The technique utilizes a unique spatial configuration of scan points of TLS to extract features, i.e. edge and corner, for autonomous dimensional quality assessment. In this paper, the dimensional quality assessment technique is further advanced so that this technique can also be applied to full-scale precast concrete panels with complex geometries. A validation test on a precast slab stored in a precast concrete factory is conducted to determine the real-life applicability of the proposed technique. In addition, a comparison with conventional deviation analysis using 3D modeling is performed. This paper is organized as follows: first, the methodology of the dimensional quality assessment technique is described. Then, a full-scale field test is presented and the result is described. Finally, this paper concludes with a brief summary and discussions for future work.

METHODOLOGY

Figure 1 illustrates the overall scheme and procedure of the dimensional quality assessment technique. It is assumed that the TLS is located at above the center of the precast concrete panel such that whole surface area of the precast panel can be scanned in a single scan. The data processing procedure starts with the acquisition of the scan points of the target precast panel via the TLS. Once 'point cloud' data is acquired from the TLS, the 3D coordinate with respect to the TLS is transformed into a new coordinate system with respect to the target (step 2). In this step, a range image generated from the scan points is used. Note that the range image is a 2D image in which each pixel of the image holds the distance value between the scan point and the TLS. Next, the background scan points are filtered and dimensional reduction from

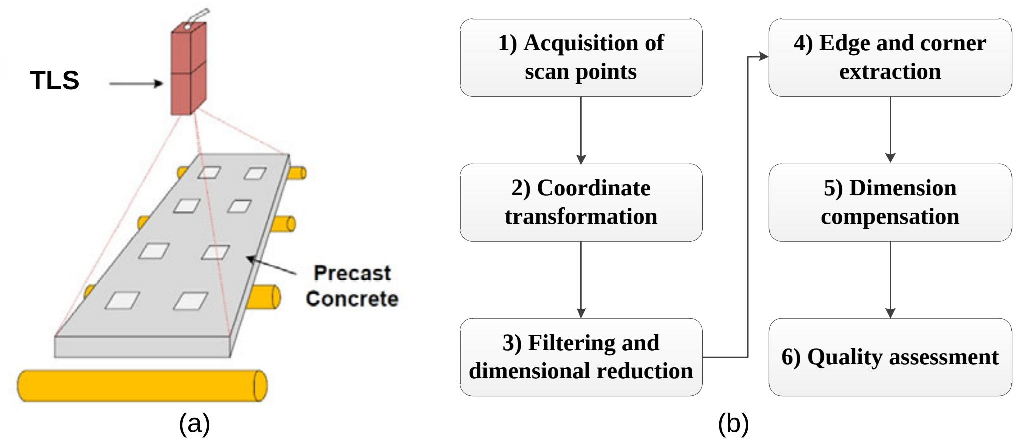

Figure 1. Overview of the dimensional quality assessment technique for precast concrete panels: (a) Overall scheme; (b) Procedures of data analysis

3D to 2D are performed (step 3). Since the scan points are well separated after the coordinate transformation process, unwanted background scan points is eliminated by setting a margin to each axis. For dimensional reduction, surface fitting is implemented and the filtered scan points are projected onto the fitted surface. Once data preprocessing is completed, edge and corner extractions are conducted (step 4). An edge extraction algorithm called a vector-sum algorithm, which was developed in the previous study (Kim et al. 2013), is implemented on the pre-processed scan points to extract only edge points along horizontal and vertical edge lines of the target panel. Once edge points are extracted, the corners of the object are then obtained by fitting the edge points of each edge line. Subsequently, the dimensions of the precast panel are initially estimated based on the corner information. However, the initially estimated dimensions are short compared to the design dimensions due to the edge loss problem caused by the TLS's mixed-pixel phenomenon (Hebert et al. 1991). Therefore, the edge loss is compensated by adding an edge loss value estimated (step 5) based on an edge loss model (Tang et al. 2009). Finally, the final decision of whether the monitored precast concrete is accepted or not is implemented by comparing the estimated dimensional errors with the corresponding tolerance (step 6). A more detailed explanation of the data processing procedure is presented in the previous work (Kim et al. 2013).

FIELD APPLICATION

To examine the applicability of the proposed dimensional quality assessment technique, field tests on a full-scale precast slab were conducted in a precast manufacturing company located in GimJe, in the Republic of Korea. The overall test configuration and the investigated precast slab are shown in Figure 2. The TLS was located above the center of the precast slab and fixed on the top of the crane. Table 1 shows the specifications of the scan parameters and the precast slab. The scanning distance of the TLS from the precast slab was 9 m, and three different angular resolutions (0.018, 0.036 and 0.072°) were investigated. The scan time for each angular resolution case were measured at 25, 8 and 4 minutes, respectively. In the field test, a precast slab with dimension of 1,980 mm × 10,610 mm was selected, and it has 16 shear pockets with identical dimension of 220 mm × 200 mm. Note that shear pocket plays a role of assembling precast concrete panels with bridge girders. The tolerance for dimensional errors is specified by the company, and they are ± 10 mm for the precast slab and ± 5 mm for the shear pocket, respectively. The specific goals of the test were to estimate 1) the dimensions of the precast slab and the shear pockets, 2) the position of the shear pockets with respect to the precast slab. Here, the position of the shear pocket is defined as the distance between the center point of a shear pocket and the closest edge of the precast slab.

Figure 3 shows the data processing results of the field test. The results were obtained from the case of angular resolution of 0.036°. Once the scan point acquisition of the precast slab was performed with the TLS, coordinate transformation based on range image was implemented. Subsequently, filtering and dimension reduction were conducted. Then, the edge points were obtained from the implementation of the vector-sum algorithm. Finally, corners were computed from intersection of the fitted edge line, and dimensional estimations for the precast slab and shear pockets were conducted based on the extracted corners and the dimensional compensation model.

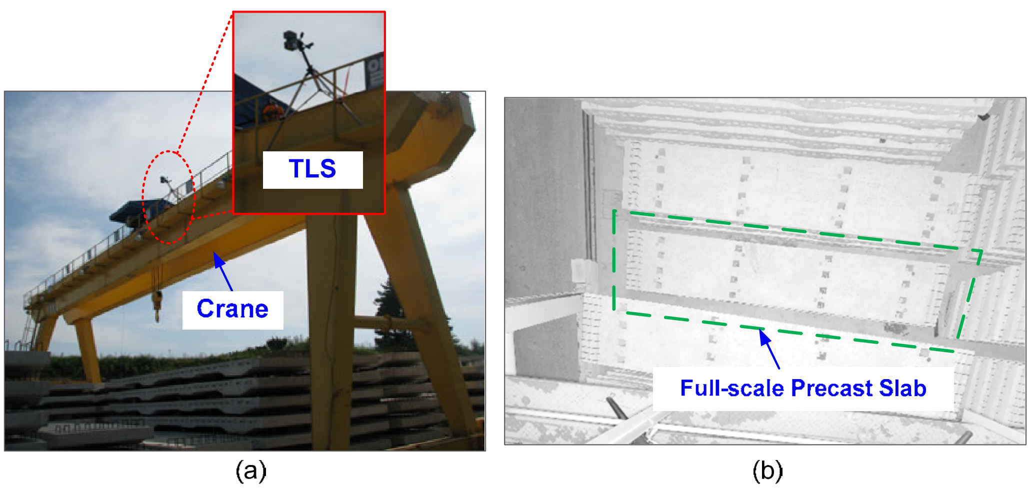

Figure 2. Field test configuration: (a) Test set-up; (b) Top view of the inspected precast slab

Table 1. Specifications of scan parameter and the precast slab

Aspect	Property	Value
Scan parameter	Scan distance	9 m
	Angular resolution	0.018, 0.036, 0.072°
	Scan time	25 (0.018°), 8 (0.036°), 4(0.072°) min.
Precast slab	Dimension	10,610 mm x 1,980 mm for precast slab 200 mm x 220 mm for shear pocket
	Specified tolerance	± 10 mm for precast slab ± 5 mm for shear pocket

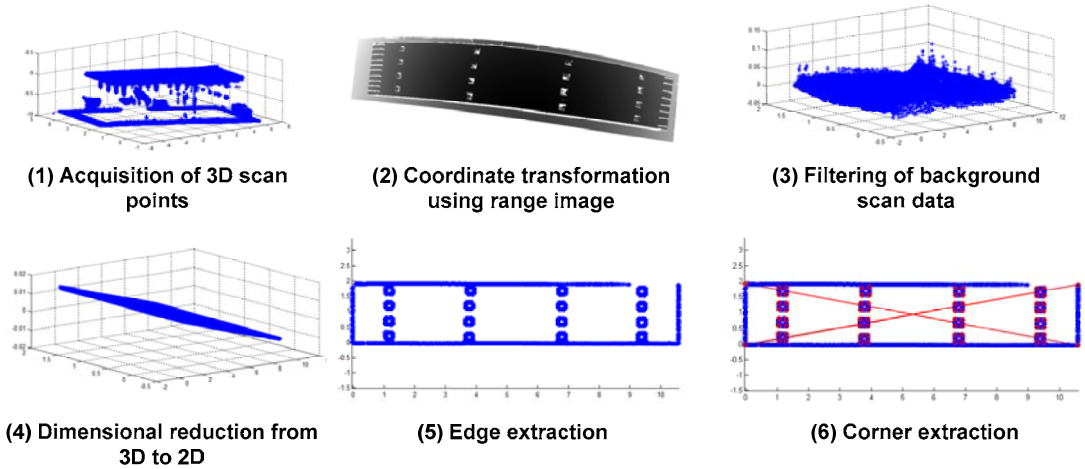

Figure 3. Data processing results of the field test

Table 2. Dimensional estimation results

Angular resolution	Dimension error (mm)				
	Length (slab)	Width (slab)	Length (shear pocket)	Width (shear pocket)	Ave.
0.072	2.3	25.6	4.1	16.0	12.0
0.036	2.7	7.3	6.2	9.0	6.3
0.018	1.0	4.7	6.6	5.8	4.5

Table 3. Position estimation results of the shear pockets

Angular resolution	Position error (mm)		
	Length	Width	Ave.
0.072	3.8	19.4	11.6
0.036	5.7	9.6	7.7
0.018	5.3	7.6	6.4

Table 2 shows the performance of the proposed dimensional estimation technique and how its accuracy varies depending on angular resolutions. The dimension error in Table 2 is defined as the difference between the actual dimension measured by manual inspection and the one estimated by the proposed technique. In the test, a total of 68 dimensions, i.e. the horizontal lengths and vertical widths of the slab and the sixteen shear pockets, were estimated from each scan. Note that the average dimension error in Table 2 is the average of these 68 dimension errors. The average dimension errors were 12.0, 6.3 and 4.5 mm for the angular resolutions of 0.072, 0.036 and 0.018°, respectively. In addition, it was observed that a dense angular resolution (small spatial resolution) provides a more accurate result than those of the coarser angular resolutions (large spatial resolution), which proves that with more scan points, a higher accuracy can be obtained.

Table 3 presents the position errors of the sixteen shear pockets estimated by the proposed technique under varying angular resolutions. The position error of each shear pocket was calculated horizontally (length) and vertically (width) so that a total of 32 position errors were obtained from each scan. The estimated position errors were 11.6, 7.7 and 6.4 mm for the angular resolution of 0.072, 0.036 and 0.018°, respectively. Similar to the dimension error results in Table 2, the estimation performance deteriorated as the angular resolution increased. It is noticeable that the vertical (width) errors appear to be relatively larger than the horizontal errors. This could be due to the fact that the vertical scan speed of the TLS is much faster (about 2000 times) than the horizontal scan speed, resulting in large measurement noises in the vertical direction (Tang et al. 2009).

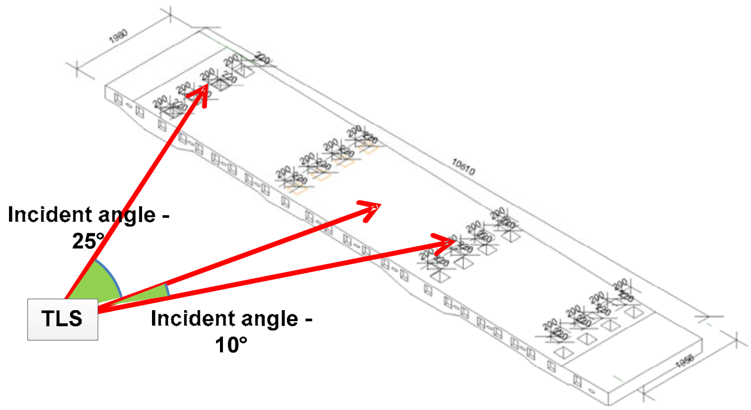

Figure 4. Effect of incident angle on dimensional estimations

In this study, some challenges encountered during the data analysis were investigated. Firstly, incident angle between the TLS and the precast slab affected the dimensional estimation results. As can be seen in Figure 4, the incident angles differ with respect to the position of the shear pockets. For example, the incident angle of the left four shear pockets near the left vertical edge of the precast slab was measured at approximately 25°, whereas the inner shear pockets have a 10° incident angle. These negatively influenced on the dimensional estimation results. A large incident angle causes deterioration in the performance of the vector-sum algorithm. Since the dimensional estimation is heavily dependent on the edge and corner extraction results, poor edge extraction results at the edge (about 30° incident angle) of the precast slab led to large dimensional errors in this study. To tackle this problem, in consideration of the different incident angles, different compensation values were adapted in this study to the initially estimated dimensions obtained from the extracted corner points. It is noticeable that a proper scan parameter selection, considering a maximum incident angle, should be preceded to ensure good dimensional estimation results. Second, external attachments on the precast slab were a barrier, preventing accurate dimension estimations. Figure 5 (a) shows the steel bar attached on the precast slab. Note that the steel bar was built to be used for lifting the precast slab although it was not included in the blueprint of the model. In Figure 5 (b), the scan points of the steel bar are reflected on the edge point extraction results. Since the inner scan points such as the scan points for the steel bar are not utilized to estimate the dimension and positions, this problem was revolved by setting a proper margin to each vertical edge line of the precast slab. With help of the coordinate transformation conducted in the pre-processing step, the elimination process of inner scan points were automatically implemented based on known information, i.e. design dimension and positions from the blueprint.

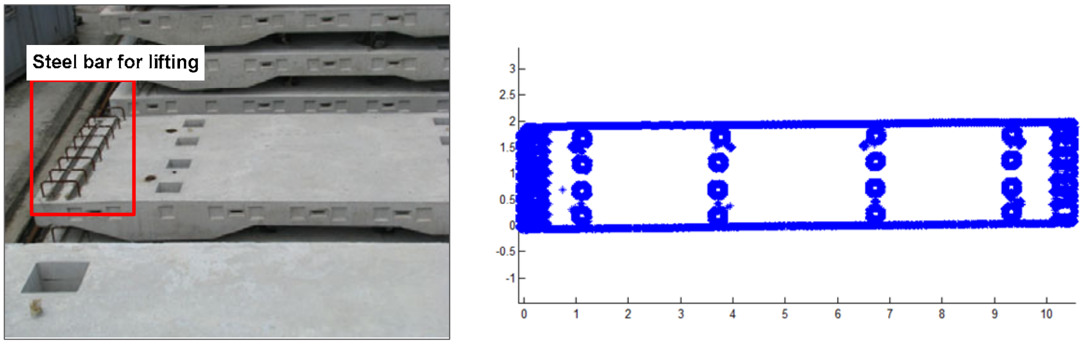

Figure 5. Effect of external attachments on edge extractions: (a) A photo of steel bar for lifting; (b) The edge extraction result containing scan points of the steel bars

DISCUSSION

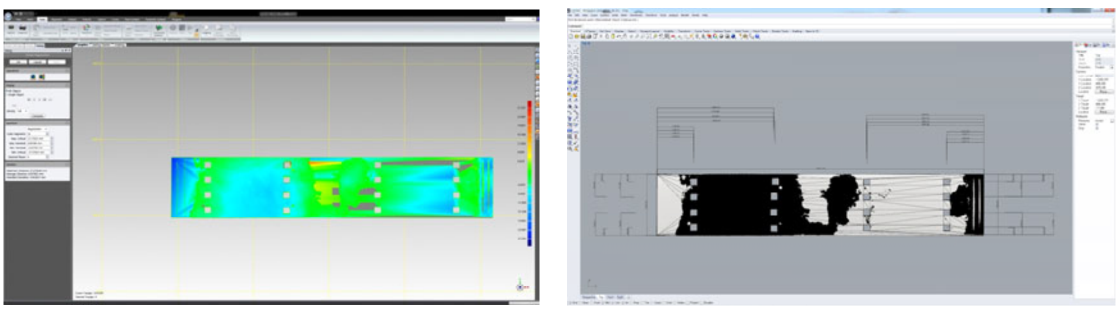

Figure 6. Deviation analysis between design model and as-built model

Table 4. Comparison of dimensional estimations with conventional method

Method	Dimension error (mm)				Position error (mm)		Ave.
	Length (slab)	Width (slab)	Length (S. P.)	Width (S. P.)	Length (S. P.)	Width (S. P.)	
Common	20.0	4.5	1.8	6.5	17.5	11.1	10.2
Developed	1.0	4.7	6.6	5.8	5.3	7.6	5.2

In order to investigate the performance of the proposed dimensional quality assessment technique compared to the conventional method, deviation analysis between the design model and the scan points was concurrently conducted. A TLS, ScanStation C10 of Leica Geosystems, was used to acquire a point cloud of 10 different position scans. For modeling and estimating the dimensions of the precast slab, Cyclone and Geomagic commercial software programs were utilized, respectively. Figure 6 shows the deviation analysis results of the as-design model and as-built model created from the modeling of the point cloud. The color indicates the different deviation levels. Table 4 summarizes the comparison result between the proposed dimensional quality assessment technique and the deviation analysis method. The average dimensional error of the deviation analysis 10.2 mm, demonstrating that the proposed technique (average dimensional error of 5.2 mm) can accurately estimate and assess the dimensional properties of the precast slab.

CONCLUSION

This paper presents the potential of the developed dimensional quality assessment technique for precast concrete panels. A field test on a full-scale precast slab with complex geometries was conducted in a precast manufacturing company to validate the real-life applicability of the developed dimensional quality assessment technique. Some challenges encountered during the data analysis of the full-scale test are discussed and resolved properly using optimized algorithms. Furthermore, comparison between the conventional method (deviation analysis) and the proposed technique was conducted. The result demonstrates that the proposed technique can accurately estimate and assess the dimensional properties of the precast concrete panel. Further investigation is underway to extend the proposed technique to other types of precast concrete panels that have more complex configurations.

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